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Prosodic strengthening on the /s/-stop cluster and the phonetic implementation of an allophonic rule in English

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ABSTRACT

This acoustic study investigates effects of boundary and prominence on the temporal structure of **s#CV** and **#sCV** in English, and on the phonetic implementation of the allophonic rule whereby a voiceless stop after /s/ becomes unaspirated. Results obtained with acoustic temporal measures for /sCV/ sequences showed that the segments at the source of prosodic strengthening (*i.e.*, /s/ in **#sCV** for boundary marking and the nucleus vowel for prominence marking) were expanded in both absolute and relational terms, whereas other durational components distant from the source (*e.g.*, stop closure duration in **#sCV**) showed temporal expansion only in the absolute measure. This suggests that speakers make an extra effort to expand the very first segment and the nucleus vowel more than the rest of the sequence in order to signal the pivotal loci of the boundary *vs.* the prominence information. The potentially ambiguous **s#CV** and **#sCV** sequences (*e.g.*, *ice#can vs. eye#scan*) were never found to be neutralized even in the phrase-internal condition, cuing the underlying syllable structures with fine phonetic detail. Most crucially, an already short lag VOT in **#sCV** (due to the allophonic rule) was shortened further under prosodic strengthening, which was interpreted as enhancement of the phonetic feature {voiceless unaspirated}. It was proposed that prosodic strengthening makes crucial reference to the phonetic feature system of the language and operates on a phonetic feature, including the one derived by a language-specific allophonic rule. An alternative account was also discussed in gestural terms in the framework of Articulatory Phonology.
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1. Introduction

One of the important goals of linguistic phonetics is an understanding of how abstract representations of sounds that are rather coarsely specified by the phonology of the language are phonetically shaped in a flow of speech. Numerous phonetic studies over the past several decades have unequivocally demonstrated that one of the pivotal factors that influence the phonetic shaping of individual segments is the prosodic structure of an utterance. Prosodic structure has been assumed to serve as a frame for articulation (*e.g.*, Beckman, 1996; Keating & Shattuck-Hufnagel, 2002), and to reflect *boundary marking* for grouping prosodic constituents (*i.e.*, *delimitative* function) and *prominence marking* for signaling information locus in the utterance by stressing particular prosodic constituents (*i.e.*, *culminative* function). Prosodic structuring of an utterance therefore modulates phonetic realization of individual segments not only at the phonetic level (determining their phonetic details), but also at the phonological level (constraining application of phonological rules).

The present study continues to explore the phonetics-prosody interface by examining how segments in **sCV** sequences ('C'=a voiceless stop) in English are realized along the temporal dimension as a function of marking prosodic boundary *vs.* prominence. It specifically examines **#sCV** (with the /s/-stop onset cluster as in 'eye#scan') and **s#CV** (with the post-lexically created /s/-stop cluster

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as in 'ice#can'). This will allow us to observe detailed phonetic manifestation of prosodic boundary and prominence on the same segmental sequences with different syllable structures as well as prosodic conditioning of the phonetic implementation of the phonological rule that a stop becomes unaspirated after /s/ in the **sCV** sequence.

1.1. Prosodic strengthening

Fine-grained but systematic phonetic variation of individual speech sounds as a function of prosodic structuring has often been discussed in terms of 'prosodic strengthening', which can be defined as spatio-temporal expansion of segments associated with important prosodic landmark locations such as edges of a prosodic domain and stressed/accented syllables (see Fletcher, 2010; Cho, 2011 for a review). The edge effects, known as final lengthening at the right edge and domain initial strengthening at the left edge of a prosodic domain, have been the loci of phonetic investigation by many researchers in efforts to illuminate how final and initial segments are realized in various contextually-adjusted phonetic forms to signal the boundary (prosodic grouping) information of prosodic structure (*e.g.*, Byrd & Saltzman, 2003; Byrd, Krivokapić, & Lee, 2006; Byrd, Lee, & Campos-Astorika, 2008; Cho, 2004, 2006, 2008; Cho & Keating, 2001, 2009; Fougeron, 2001; Fougeron & Keating, 1997; Keating, Cho, Fougeron, & Hsu, 2003; Krivokapić, 2007; Krivokapić & Byrd, 2012; *inter alia*). Another type of prosodic strengthening is prominence-induced strengthening driven by accent/stress marking, which renders a particular prosodic unit (usually a syllable or a word) phonetically more salient than other units in a phrase (Beckman, Edwards, & Fletcher, 1992; Cho, 2006; Cho & Keating, 2009; de Jong, 1995, 2004; Fowler, 1995; Lehiste, 1970; *inter alia*). This latter type of prosodic strengthening is often assumed to be linked with enhancement of distinctive features, bringing about maximizing phonemic (and lexical) contrasts, and is used, especially when realized with focus, as a diagnostic for what phonetic content is used to mark phonemic contrast in a given language (de Jong, 2004; de Jong & Zawaydeh, 2002).

Despite the growing body of studies on prosodic strengthening as discussed above, however, we are still left with a number of questions to be answered. Some of the questions are generally centered around the issues regarding how precisely the scopes (or the domains) of boundary *vs.* prominence marking are determined and how they are constrained by various factors such as allophonic rules of a given language and syllable structure. The goal of the present study is to explore these questions by investigating how the acoustic temporal realizations of individual segments in **sCV** sequences are modulated by boundary- and prominence-induced prosodic strengthening factors; how the distribution of temporal effects of prosodic strengthening is further conditioned by syllable structure (**s#CV** *vs.* **#sCV**)[1]; and how prosodic strengthening relates to phonetic implementation of a language-specific allophonic rule in English in connection with enhancement of phonetic feature. The acoustic temporal measures to be explored for the **sCV** sequence include /s/-duration, stop closure duration, VOT and vowel duration. Specific research questions that the present study particularly aims to answer are discussed in the following section.

1.2. Research questions

1.2.1. How does the boundary effect interact with the prominence effect on the temporal realization of #sCV?

Byrd and Choi (2010), in an electromagnetic midsagittal articulometer (EMMA) study, examined the boundary effect on #CCV sequences in English, showing that the stop as the second member of **#sC** may undergo domain-initial lengthening, but not as robustly as when it was initial in **s#C**. This was interpreted as supporting the predictions made by the theory of the π-gesture—*i.e.*, the boundary-induced lengthening effect is strongest at the boundary and becomes gradually weaker as a function of the segment's proximity to the boundary (*e.g.*, Byrd & Saltzman, 2003; Byrd et al., 2006; Krivokapić & Byrd, 2012; *cf.* Cho & Keating, 2009). The prominence effect, on the other hand, is assumed to be centered around the vowel (the nucleus) and to possibly spread leftward to adjacent segments in a gradually attenuating fashion (*e.g.*, Turk & White, 1999; White & Turk, 2010). Byrd and Choi, however, did not systematically take into account strengthening effects arising from prominence, leaving it unclear how the reported boundary effect would interact with prominence. We therefore extend Byrd and Choi by examining boundary-prominence interactions along the acoustic-temporal dimension.

While it is an open question exactly how boundary interacts with prominence in the temporal realization of **#sCV**, some predictions can be made as follows. Considering the segment's proximity to the boundary as discussed above, the first member of the cluster should demonstrate the strongest boundary lengthening effect, and the effect is expected to be *prominence-independent* (*i.e.*, regardless of whether the target-bearing word is accented or not). This would be because /s/ is initial (**#sCV**) and at the same time is farthest away from the nucleus vowel, the source of prominence-induced strengthening. Compared to /s/, the stop 'C', the second member of the cluster should then show a relatively weaker boundary effect as it is farther away from the boundary and at the same time closer to the locus of prominence (the nucleus vowel), being more vulnerable to the prominence effect. Given that the boundary effect on the consonantal articulation is often obscured by the prominence effect (Cho & Keating 2009; Cho, Lee, & Kim, 2011), we expect the boundary-induced lengthening effect on the stop in **#sCV** to be *prominence-sensitive*, such that it may be weakened or unobservable under accent, while it may surface robustly when it is free of the influence of prominence (*i.e.*, when unaccented). Lastly, the boundary lengthening effect on the following vowel is expected to be weakest or completely absent as the vowel in **#sCV** is not only farther away from the boundary but it also becomes the locus of prominence.

[1] The syllable structure factor is confounded with the location of the word boundary, but these factors cannot be teased apart as the location of the word boundary determines a simplex (s#C) vs. a complex (#sC) onset.

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